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# An Early Eocene age for the Quilchena fossil locality, southern British Columbia

Mike Villeneuve and Rolf Mathewes

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**Abstract:** The Quilchena fossil site is a rich repository of Eocene (Ypresian) plant, insect, and fish fossils. Although its age has long been correlated with many other 'mid-Eocene' localities in the Okanagan Highlands, the radiometric age has been variable and inconclusive. Data presented here, using U-Pb dating of zircons from a thick tephra, combined with $^{40}Ar$-$^{39}Ar$ dating of sanidine crystals from the same bed, confirm the age of the Quilchena deposit as Early Eocene (51.5 ± 0.4 Ma). This age can be securely ascribed to the Quilchena fossils, since the dated tephra was deposited within the fossil-bearing shale and mudstone sequences. The paleontological and paleoclimatic significance of this age assignment will become clearer as other fossil sites in the Okanagan Highlands are radiometrically dated with similar methods and compared with the Quilchena locality.

**Résumé :** Le gîte fossilifère de Quilchena constitue un riche dépôt de fossiles de plantes, d'insectes et de poissons de l'Éocène (Yprésien). Bien que des corrélations aient été depuis longtemps établies entre son âge et celui d'un grand nombre d'autres localités de l'« Éocène moyen » dans les hautes terres d'Okanagan, l'âge radiométrique obtenu pour ce site s'est avéré variable et non décisif. Les données ici présentées, basées sur des datations U-Pb de zircons provenant d'un épais téphra combinées à des datations $^{40}Ar$-$^{39}Ar$ de cristaux de sanidine provenant du même lit, confirment que le dépôt de Quilchena remonte à l'Éocène précoce (51,5 ± 0,4 Ma). On peut avec confiance attribuer cet âge aux fossiles de Quilchena puisque le téphra daté a été déposé au sein des séquences fossilifères de shale et de mudstone. La portée paléontologique et paléoclimatique de cette datation se précisera au fur et à mesure que d'autres sites fossilifères des hautes terres d'Okanagan seront datés par des méthodes radiométriques similaires et comparés avec l'emplacement de Quilchena.

## INTRODUCTION

The Okanagan Highlands is an upland region approximately 1000 km long, stretching from Republic, Washington in the south, northwest to the Driftwood Creek fossil locality of British Columbia (Fig. 1). A number of other well known Early Tertiary fossil sites, including Princeton, Quilchena, McAbee, Chu Chua, Horsefly, and others, are found within this montane area. These localities contain diverse and often exquisitely preserved floras and faunas that have usually been assigned a Lutetian (48.6 ± 0.2 Ma to 40.4 ± 0.2 Ma; Gradstein et al., 2004) age (Wolfe and Wehr, 1987; Wehr, 1995). The significance of these fossil assemblages is becoming recognized for insights regarding evolutionary events and for climatic-change studies (Wolfe and Wehr, 1981, 1987; Archibald and Mathewes, 2000; Greenwood et al., 2005). The Ypresian (55.8 ± 0.2 Ma to 48.6 ± 0.2 Ma; Gradstein et al., 2004) is acknowledged as the warmest part of the Cenozoic, with peak terrestrial warmth occurring around 52 Ma (Wing et al., 1991; Zachos et al., 2001). It is therefore important to establish the ages of the various floras and faunas relative to this warm interval and to one another, so that climate and other environmental parameters can be accurately estimated.

Special significance has been ascribed to the plants from these Eocene sites, particularly the extensively studied fossils of vegetative and reproductive structures from the Republic locality (Wolfe and Wehr, 1987; Wehr, 1995). It has been noted (Wehr and Hopkins, 1994) that many modern dicot plant genera make their earliest or best documented appearance in the fossil record of the Okanagan Highlands, including many familiar members of the rose family (Rosaceae), such as *Amelanchier* (Saskatoon berry), *Prunus* (cherry and plum), *Crataegus* (hawthorn), *Sorbus* (mountain ash), and others. Also found at many sites are a number of extinct plants with form genus names, such as *Florissantia*, *Cedrelospermum*, *Cruciptera*, *Deviacer*, *Paleocarpinus*, *Plafkeria*, and *Nordenskioldia*, that generate interesting questions regarding the role of climate in extinction and the former existence of biogeographic connections to Asia via Beringia or to Europe via Greenland (Manchester, 1999). Also of interest biogeographically is the presence of several angiosperms that are now found in the wild only in eastern Asia, including *Eucommia* (Chinese rubber tree) and *Dipteronia*, a close relative of maples.

Reliable age assignment is critical in order to reconstruct the biogeographic, climatic, and evolutionary relationships between the floras and faunas of the Okanagan Highlands and those of other Tertiary sites around the world.

### *Geology and previous age assignments*

The fossil localities of the Okanagan Highlands are mostly exposures of ancient lake and associated sediments that accumulated in upland basins formed by extensional faulting. This faulting was accompanied by regional volcanism with extensive lava flows and widespread airfall tephra deposits. Ewing (1980, 1981) suggested that this process began regionally in the Early Eocene, about 53 Ma, and classified the basin fills of the Kamloops and Quilchena areas as part of the

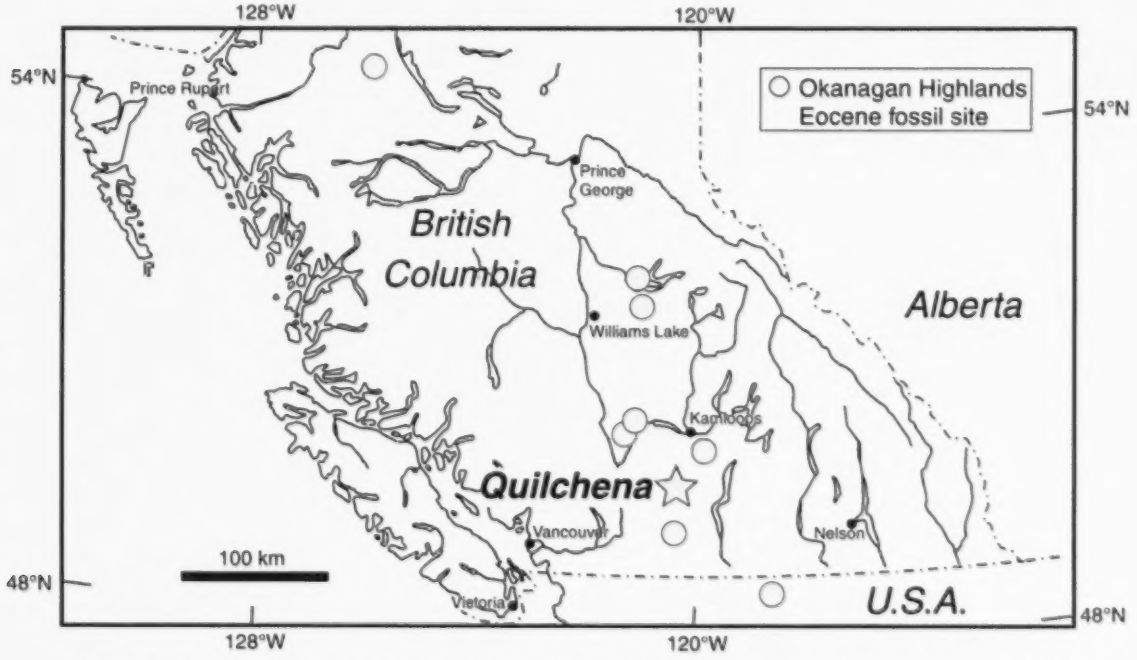


***Figure 1.*** *Location of Eocene fossil occurrences in the Okanagan Highlands of south-central British Columbia. Location of the Quilchena occurrence is marked by a star.*

Kamloops Group. Earlier paleontological studies, however, suggested an age younger than Eocene for these sites (Penhallow, 1908; Cockfield, 1948). Cockfield cited evidence from plant fossils that the Coldwater beds at Merritt and Quilchena were probably of lower Miocene to Oligocene age, based on similarities to rocks in the Kitsilano area of Vancouver (now known as the Huntington Formation), although these strata are now known to be Late Paleocene to Eocene (Mustard and Rouse, 1994).

With the advent of K-Ar dating (K-Ar ages have been recalculated to the decay constants of Steiger and Jäger (1977)), Rouse and Mathews (1961) analyzed four biotite-bearing volcanic rocks in the Princeton and Kamloops areas, and concluded that these fossil sites were Middle Eocene (50–46 Ma) in age. Hills (1965) and Hills and Baadsgaard (1967) investigated Quilchena rocks among many others, using K-Ar on bentonite minerals. One sample from Quilchena dated as expected (50 Ma) along with 15 other Middle Eocene ages, ranging between 53 and 47 Ma. Two other Quilchena samples, however, were wildly divergent (Hills and Baadsgaard, 1967). A Miocene age (22 Ma) on volcanic glass shards was attributed to argon loss, and a Cretaceous age (81 Ma) was likely caused by reworking of older rock fragments into the bentonite. It is also important to note that these data were collected during the infancy of K-Ar analysis and lack corrections (such as for atmospheric Ar) or attendant data (such as error analysis) that would help corroborate the robustness of the age. The disparity in the existing dataset, coupled with the absence of dates obtained with modern geochronometric methods, highlights the need for new data to clarify the age of the Quilchena fossil beds.

### *Quilchena Creek fossil locality*

Sediments of the 'Quilchena coal basin' accumulated in a fault-bounded graben, measuring approximately 11 km long from north to south and 3 km wide, south of Nicola Lake (Fig. 1). Fossiliferous exposures are uncommon, since most of the basin is draped by glacial drift and recent alluvium and colluvium. Conglomerate, sandstone, mudstone, shale, and occasional coal seams are known from the basin, along with bentonite layers and other tephra-derived sediments. The Coldwater beds unconformably overlie rocks of the Triassic Nicola Group (Cockfield, 1948). The 50 Ma K-Ar date cited by Hills (1965) came from a bentonite exposure on the eastern side of the valley, but the stratigraphic relationship between this and the Quilchena locality is unknown.

The fossil-bearing lacustrine rocks studied in this report are exposed in a small (approx. 28 m long) roadcut on the western bank of Quilchena Creek (lat. 50° 7.667'N, long. 120° 30.354'W), about 3.5 km south of the Quilchena Hotel. Thousands of plant remains, abundant insects with various other invertebrates, and abundant fish remains have been recovered from this locality, which has been studied by Mathewes and Brooke (1971), Guthrie (1985), Wilson (1987), Archibald and Mathewes (2000), Greenwood et al. (2005), and others. Many of the fossils represent unique occurrences in some way — either as first-known fossil records, unusual abundances, unusual combinations of environmental-indicator taxa, or new taxa. For example, Quilchena is the only Okanagan Highlands locality with an extensive and diverse ant fauna, bee-body fossils, the most complete fossil earwig, and new fossil species of lacewings, true bugs, and other insects (Archibald and Mathewes, 2000). The paleobotanical data for Quilchena have recently been used to reconstruct climatic conditions during the Eocene, using leaf-margin analysis and nearest-living-relative bioclimatic approaches to estimate temperatures and precipitation for comparison with other localities (Greenwood et al., 2005). These data suggest that Quilchena was both the warmest and the wettest of the Okanagan sites, a condition that might be related to differences in paleoelevation or age when compared to other sites.

Guthrie (1985) excavated and mapped the sedimentary rocks in detail at the Quilchena Creek exposure. He determined that two facies are exposed here in a southward-dipping sequence, representing 'offshore' and 'nearshore' depositional environments of a shallow paleolake. The northern end of the roadcut is dominated by fine, platy, paper shale, interpreted as an offshore (facies 1) unit. This grades upward into more massive, often concretionary sandy mudstone toward the southern end, interpreted as a more energetic nearshore facies 2. Many thin and discontinuous bentonitic layers are scattered throughout the exposure, and a thick, relatively unweathered tephra bed is found in facies 2 (Fig. 2). The mudstone and the light-coloured sandy tephra are bounded by sharp contacts. Two separate samples of the indurated basal tephra were collected by RWM and sent to MV at the Geological Survey of Canada for processing and radiometric-age determination.

## METHODOLOGY

### *Determination of U-Pb ages*

Following the separation of heavy minerals using heavy liquids, samples were passed through a Frantz LB-1J magnetic separator to purify the zircon fraction. Zircon crystals were selected for analysis based on criteria that optimized their

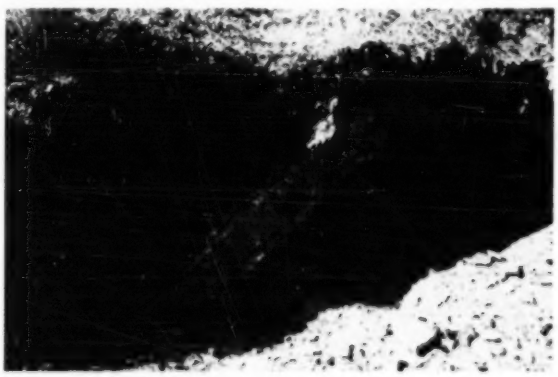

***Figure 2.*** *Photograph of dated white tuffaceous layer (approx. 30 cm in stratigraphic thickness) within mudstone at Quilchena Creek, south-central British Columbia.*

clarity, lack of cloudiness and colour, and lack of fractures. All zircons were abraded prior to analysis to increase concordance by removing the outer portions of the grains where much of the Pb loss and alteration take place (Krogh, 1982). Following abrasion, photography, and final mineral selection, mineral fractions were analyzed according to methods summarized in Parrish et al. (1987). Data have been reduced and errors have been propagated using software written by J.C. Roddick; error propagation was done by numerical methods (Parrish et al., 1987; Roddick, 1987). Error ellipses on concordia diagrams are shown at the 2σ (95% confidence) level of uncertainty. Final errors are indicated in Table 1. Linear regressions on discordant arrays of data use a modified York (1969) method that takes into account the scatter of the points about the line (*see* discussion in Parrish et al., 1987). Fraction letters shown on concordia diagrams are keyed to the fraction letters in Table 1.

### *Determination of $^{40}Ar$-$^{39}Ar$ ages*

The sample was crushed, cleaned, and passed through heavy liquids of density 2.58, resulting in flotation of sanidine crystals. Clear, colourless, unaltered sanidine crystals approximately 0.5 mm diameter were then hand-picked. These were loaded into aluminum foil packets bracketed between grains of Fish Canyon Tuff Sanidine to act as flux monitor (apparent age 28.03 ± 0.1 Ma; Renne et al., 1994). The sample packets were arranged radially inside an aluminum can and then irradiated for 12 hours at the research reactor of McMaster University in a fast neutron flux of approximately 3 x $10^{16}$ neutrons/cm$^2$.

Upon return from the reactor, samples were split into several aliquots and loaded into individual 1.5 mm diameter holes in a copper planchet. Laser $^{40}Ar$-$^{39}Ar$ step-heating analysis was carried out at the Geological Survey of Canada laboratories in Ottawa, Ontario. The planchet was then placed

**Table 1:** Uranium-lead data, Quilchena fossil locality, southern British Columbia.

| Fraction[a] | Wt.[b] (µg) | U (ppm) | Pb[c] (ppm) | $^{206}Pb/^{204}Pb$[d] | Pb[e] (pg) | $^{208}Pb/^{206}Pb$[f] | Radiogenic ratios (±1σ in %)[f] | | | Age (Ma, ±2σ) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $^{207}Pb/^{235}U$ | $^{206}Pb/^{238}U$ | $^{207}Pb/^{206}Pb$ | $^{207}Pb/^{235}U$ | $^{206}Pb/^{238}U$ | $^{207}Pb/^{206}Pb$ |
| **Quilchena Creek Tuff (Z4769; 50° 07' 40"N, 120° 30' 20"W)** | | | | | | | | | | | | |
| 1A-2 (Z) | 65 | 177 | 3 | 1632 | 6 | 0.16 | 0.10421 ± 0.00017 | 0.01428 ± 0.00002 | 0.05293 ± 0.00006 | 325.8 ± 5.4 | 325.8 ± 5.4 | 325.8 ± 5.4 |
| 1B-2 (Z) | 79 | 116 | 3 | 4018 | 3 | 0.14 | 0.25846 ± 0.00028 | 0.02535 ± 0.00002 | 0.07396 ± 0.00004 | 1040.3 ± 2.3 | 1040.3 ± 2.3 | 1040.3 ± 2.3 |
| 2A-2 (Z) | 39 | 351 | 3 | 1826 | 4 | 0.25 | 0.05529 ± 0.00010 | 0.00848 ± 0.00001 | 0.04726 ± 0.00007 | 62.4 ± 7.0 | 62.4 ± 7.0 | 62.4 ± 7.0 |
| 2B-2 (Z) | 35 | 145 | 1 | 162.7 | 19 | 0.25 | 0.06045 ± 0.00074 | 0.00903 ± 0.00003 | 0.04853 ± 0.00050 | 125 ± 47.8 | 125 ± 47.8 | 125 ± 47.8 |
| 2C-2 (Z) | 22 | 400 | 4 | 1738 | 3 | 0.27 | 0.05313 ± 0.00013 | 0.00813 ± 0.00002 | 0.04737 ± 0.00009 | 68.1 ± 8.9 | 68.1 ± 8.9 | 68.1 ± 8.9 |
| A2-1 (Z) | 24 | 502 | 6 | 651.7 | 12 | 0.21 | 0.07034 ± 0.00020 | 0.01061 ± 0.00001 | 0.04809 ± 0.00011 | 103.9 ± 11.1 | 103.9 ± 11.1 | 103.9 ± 11.1 |
| B-1 (Z) | 33 | 509 | 4 | 116.6 | 88 | 0.18 | 0.05387 ± 0.00096 | 0.00831 ± 0.00004 | 0.04701 ± 0.00069 | 49.9 ± 68.7 | 49.9 ± 68.7 | 49.9 ± 68.7 |
| C-1 (Z) | 30 | 459 | 18 | 5296 | 6 | 0.21 | 0.42402 ± 0.00046 | 0.03581 ± 0.00003 | 0.08589 ± 0.00003 | 1335.6 ± 1.5 | 1335.6 ± 1.5 | 1335.6 ± 1.5 |

[a]All zircon fractions are abraded; (Z)=Zircon
[b]Error on weight = ± 0.001 µg
[c]Radiogenic Pb
[d]Measured ratio corrected for spike and Pb fractionation of 0.09 ± 0.03%/AMU
[e]Total common Pb on analysis corrected for fractionation and spike of blank model Pb composition
[f]Corrected for blank and spike Pb and U and common Pb (Stacey-Kramers model Pb equal to the $^{206}Pb/^{238}U$ age)

**Table 2:** Argon-argon data, Quilchena fossil locality, southern British Columbia.

| Power[a] | Volume $^{39}Ar$ x$10^{-11}$ cc | $^{36}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{38}Ar/^{39}Ar$ | $^{40}Ar/^{39}Ar$ | %$^{40}Ar$ ATM | $^{40}Ar/^{39}Ar$ | $f_{39}$[b] (%) | Apparent Age Ma[c] |
|---|---|---|---|---|---|---|---|---|---|
| **QUILCHENA Sanidine (z4769) J=0.003038 ± 0.000018[d]** | | | | | | | | | |
| Aliquot: A | | | | | | | | | |
| 3.0 | 0.119 | 0.0602 ± 0.0195 | 1.296 ± 0.049 | 0.071 ± 0.014 | 37.110 ± 1.426 | 45.4 | 20.265 ± 3.021 | 0.4 | 107.79 ± 15.60 |
| 3.9 | 0.7681 | 0.0030 ± 0.0031 | 0.042 ± 0.004 | 0.010 ± 0.011 | 10.441 ± 0.196 | 6.4 | 9.776 ± 0.476 | 2.4 | 52.80 ± 2.53 |
| 4.6 | 0.7737 | 0.0020 ± 0.0030 | 0.026 ± 0.003 | 0.008 ± 0.011 | 10.117 ± 0.210 | 3.8 | 9.734 ± 0.451 | 2.5 | 52.58 ± 2.40 |
| 5.5 | 0.7602 | 0.0015 ± 0.0031 | 0.023 ± 0.004 | 0.009 ± 0.011 | 9.973 ± 0.201 | 2.2 | 9.752 ± 0.456 | 2.4 | 52.68 ± 2.43 |
| 12.0 | 4.9469 | 0.0009 ± 0.0005 | 0.014 ± 0.000 | 0.002 ± 0.011 | 9.779 ± 0.054 | 2.2 | 9.560 ± 0.082 | 15.6 | 51.65 ± 0.44 |
| Aliquot: B | | | | | | | | | |
| 3.9 | 0.673 | 0.0162 ± 0.0036 | 0.244 ± 0.009 | 0.005 ± 0.011 | 13.953 ± 0.238 | 32.6 | 9.398 ± 0.576 | 2.1 | 50.79 ± 3.07 |
| 4.6 | 8.3378 | 0.0005 ± 0.0003 | 0.016 ± 0.001 | 0.004 ± 0.011 | 9.642 ± 0.056 | 1.3 | 9.519 ± 0.069 | 26.4 | 51.44 ± 0.37 |
| 5.5 | 5.3821 | 0.0003 ± 0.0004 | 0.012 ± 0.001 | 0.003 ± 0.011 | 9.610 ± 0.048 | 0.7 | 9.544 ± 0.073 | 17 | 51.57 ± 0.39 |
| 12.0 | 9.8617 | 0.0004 ± 0.0003 | 0.010 ± 0.000 | 0.002 ± 0.011 | 9.641 ± 0.039 | 1.1 | 9.530 ± 0.056 | 31.2 | 51.50 ± 0.30 |

[a]As measured by laser in % of full nominal power (10W)
[b]Fraction $^{39}Ar$ as percent of total run
[c]Errors are analytical only and do not reflect error in irradiation parameter J
[d]Nominal J, referenced to FCT-SAN=28.03 Ma (Renne et al., 1994)
All uncertainties quoted at 2σ level

in the extraction line and the system evacuated. Heating of individual sample aliquots in steps of increasing temperature was achieved using a Merchantek MIR10 10W $CO_2$ laser equipped with a 2 mm x 2 mm flat-field lens. The released Ar gas was cleaned over getters for ten minutes and then analyzed isotopically using the secondary electron-multiplier system of a VG3600 gas-source mass spectrometer; details of data-collection protocols can be found in Villeneuve and MacIntyre (1997) and Villeneuve et al. (2000). Neutron-flux gradients throughout the sample canister were evaluated by analyzing the sanidine flux monitors and interpolating a linear fit against calculated J-factor and sample position.

Corrected argon isotopic data are listed in Table 2 and presented as spectra of gas release, with each gas-release spectrum displaying stepheating data from the two aliquots analyzed, alternately shaded. Such plots provide a visual image of replicated heating profiles, evidence for Ar loss in the low-temperature steps, and the error and apparent age of each step.

Because the error associated with the J-factor is systematic and not related to individual analyses, correction for this uncertainty is not applied until calculation of the final age (Roddick, 1988). The error on individual J-factor values is conservatively estimated at ±0.6% (2σ). No evidence for excess $^{40}Ar$ was observed in any of the samples, so all regressions are assumed to pass through the $^{40}Ar$-$^{36}Ar$ value for atmospheric air (295.5). All errors are quoted at the 2σ level of uncertainty.

## RESULTS AND DISCUSSION

Zircons were separated from two different collections of the same bentonite layer (bed 21). The initial sample collected was small (<500 g) but contained sufficient fine-grained (<62 µm average dimension), moderate-quality (Table 1) zircon to create three multigrain fractions. Although they consist of minimal quantities of zircon, analysis of these fractions (A2-1, B-1, C-1; Table 1) resulted in one concordant fraction with a $^{206}Pb/^{238}U$ age of 53.4 Ma, albeit with large uncertainty of ±0.6 Ma due to high common Pb correction. The two other fractions clearly included xenocrysts of differing ages, as evidenced by the noncollinear array of data (Fig. 3). As such, the poorly defined lower intercept, primarily defined by the concordant point 1-B, suggests an Eocene age for the unit.

A subsequent re-collection of a larger sample resulted in the separation of abundant, high-quality zircon, with two fractions consisting of clear, euhedral, equant to elongate grains greater than 74 µm in size. The morphologically similar fractions consisted of grains in the 62 to 74 µm size range. The fractions consisting of larger zircons contain unmistakable inherited components, as does fraction 2B-2 from the finer grained fractions. Fractions 2A-2 and 2C-2 are both nearly concordant results that bracket the poorly defined concordant analysis B-1. Two alternative interpretations are possible. Fraction 2A-2 can be

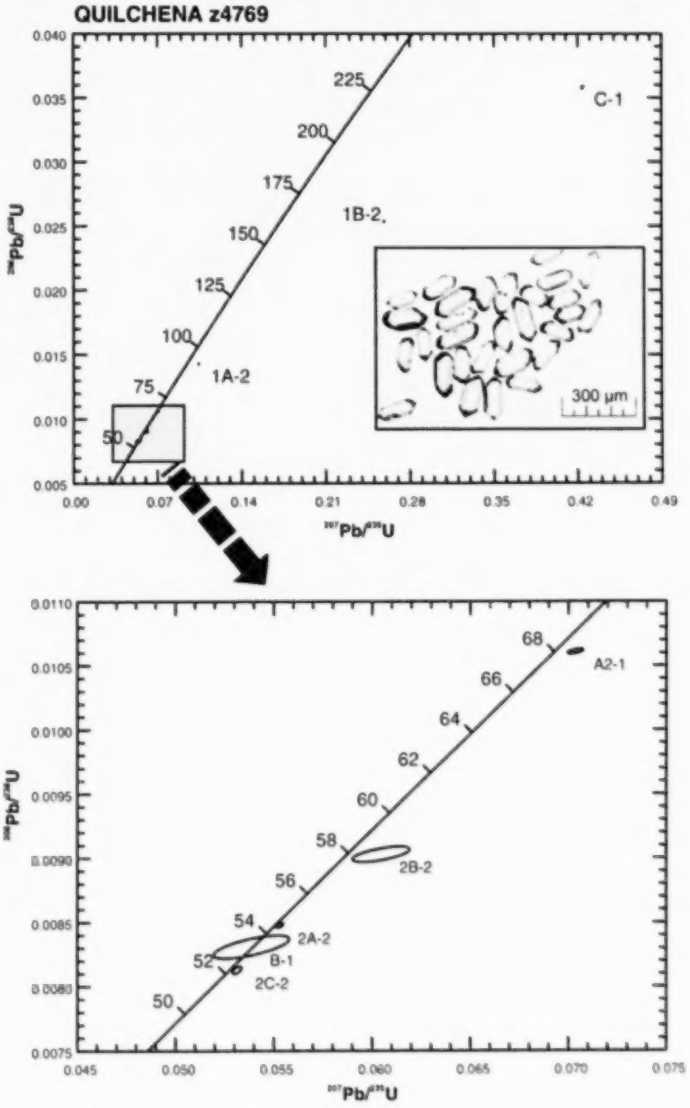


*Figure 3. Concordia plots combining zircon fractions from both sample collections (marked as '-1' and '-2'' following fraction letter), Quilchena occurrence, south-central British Columbia. Grey area in upper plot is the region magnified in the lower plot to highlight concordant to near-concordant analyses. Inset is representative of typical range of zircon morphology from second sample collection.*

used to mark the upper intercept of a Pb-loss array defined by B-1 and 2C-2, resulting in a weighted mean $^{207}Pb/^{206}Pb$ age of 64.5 ± 5.4 Ma (MSWD = 0.5). Equally possible is the inference that fraction 2C-2 constrains the lower intercept of a series of fractions (e.g. A2-1, 2B-2, 2A-2, B-1, and 2C-2) that give a lower interce±pt age of 49 +4/-11 Ma (MSWD = 3). Finally, a combination of both scenarios is possible, with the actual age approximated by concordant fraction B-1 and other fractions displaying Pb loss or inheritance, as appropriate.

In order to constrain these possibilities, sanidine crystals were separated from the re-collected sample and prepared for $^{39}Ar$-$^{40}Ar$ geochronological analysis. The sanidine grains were clear, colourless, and of equal size but generally small (approx. 200 µm diameter). These grains were co-irradiated and two aliquots consisting of 11 grains each were loaded and analyzed with the $CO_2$ laser-extraction system. Both aliquots gave reproducibly flat plateaus (Fig. 4), as defined by three or more contiguous heating steps containing greater than 60% of the released gas and falling within 2σ error. The reproducible ages for the two aliquots indicate either that sanidine is solely a primary magmatic phase or that the sub-200°C closure temperature of the mineral resulted in all grains, both primary and xenocrystic, having their K-Ar systematics reset concomitant with eruption. In either case, the age of the tuff is determined by combining data from the two aliquots and applying J-factor uncertainty, resulting in a date of 51.5 ± 0.4 Ma.

Although care must be taken when comparing U-Pb and $^{39}Ar$-$^{40}Ar$ ages (Renne et al., 1998; Min et al., 2000; Begemann et al., 2001), intercalibration of the two isotopic systems is possible (Villeneuve et al., 2000) when an appropriately chosen value for the flux monitor is used. The youngest $^{206}Pb/^{238}U$ age for zircon is 52.2 ± 0.2 Ma, approximately 0.7 Ma older than the $^{39}Ar$-$^{40}Ar$ age, indicating that inheritance is ubiquitous within the zircon fractions and serving as a caution against using the youngest $^{206}Pb/^{238}U$ ages as proxy for age and error.

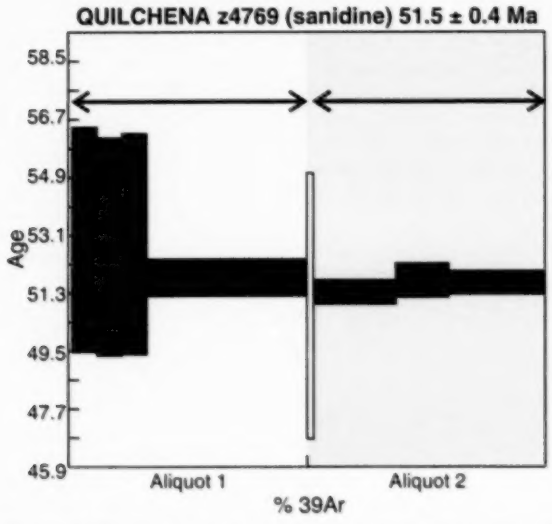


*Figure 4. Gas-release plot from replicate analysis of sanidine grains separated from Quilchena tuff, south-central British Columbia. Plateau regions are marked by line with arrowheads above the selected steps.*

Quilchena is important because it represents the first appearance of many plant taxa in the region. The $^{39}Ar$-$^{40}Ar$ age places the strata in the Early Eocene (Ypresian), older than previous K-Ar dating would support. Given the suspect nature of the earlier dataset, however, this age now allows robust correlation with other Okanagan Highland sites as they become dated (Archibald and Mathewes, 2000; Greenwood et al., 2005). It is known that Quilchena is the warmest and wettest of Okanagan Highlands sites studied so far, suggesting that it was either older (i.e. warmer because of proximity to the thermal maximum ca. 52–53 Ma) or at a lower elevation. As such, this age allows for correlation of paleotemperature data derived from the near–sea level localities in the Puget and Fraser lowlands, and serves as a basis for calculation of paleoaltitudes of the Okanagan Highlands sites (Wolfe et al., 1998).

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